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(57) Claim

1. An electrical signal control means comprising means for receiving a transmitted data signal, means for decoding the received signal, means for generating and delivering current signals to a desired point in a circuit according to the decoded information, characterized by means for actively controlling said current signal to deliver or return a predetermined amount of said current signal whereby the net current at the desired point is controlled.

2. A receiver/stimulator for a hearing prosthesis comprising means for receiving a transmitted data signal, means for decoding the received signal, means for generating and delivering current signals to a multiplicity of implanted electrodes according to the decoded information, characterized by means for actively controlling each electrode to deliver or return a predetermined amount of said current signals whereby the current distribution along the multiplicity of electrodes is controlled.

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COMPLETE SPECIFICATION

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LODGED AT SUB-OFFICE
22 AUG 1983
Melbourne

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Complete Specification for the invention entitled: "RECEIVER/STIMULATOR FOR HEARING PROSTHESIS"

The following statement is a full description of this invention, including the best method of performing it known to me:-

Note: The description is to be typed in double spacing, pica type face, in an area not exceeding 250 mm in depth and 160 mm in width, on tough white paper of good quality and it is to be inserted inside this form

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Form 1.
Regulation 9

APPLICATION FOR A STANDARD PATENT

xx WE, THE UNIVERSITY OF MELBOURNE

of Grattan Street, Parkville, Victoria, 3052, Australia

COMPLETE AFTER PROVISIONAL SPECIFICATION No. 18194/83

hereby apply for the grant of a Standard Patent ~~Patent of Addition~~ for an invention entitled

RECEIVER/STIMULATOR FOR HEARING PROSTHESIS

which is described in the accompanying provisional ~~complete~~ specification.

For a Convention application - details of basic application(s) -

NUMBER	COUNTRY	DATE OF APPLICATION

My address for service is C/- SANDERCOCK, SMITH & BEADLE
203 Riversdale Road, (P.O. Box 410) Hawthorn. Victoria 3122.

Dated this 20th day of August, 19 82

LODGED AT SUB-OFFICE 20 AUG 1982 Melbourne

(Signature)

BY: SANDERCOCK, SMITH & BEADLE

TO:

THE COMMISSIONER OF PATENTS

This form must be accompanied by either a provisional specification (Form 9 and true copy) or by a complete specification (Form 10 and true copy).

This invention relates to receiver/stimulator means for use in hearing prostheses intended to restore some hearing to the profoundly or totally deaf and in other biomedical applications, such as pacemakers. The invention may also have broader application to electrical circuitry in general.

In our patent applications Nos. AU-B 41061/78 and AU-B 59812/80 we have described various aspects of a hearing prosthesis system of the above type. In the preferred realizations of this system, the implanted hearing prosthesis comprises three basic components: a receiver/stimulator implanted in the mastoid process, an electrode array implanted in the scala tympani of the inner ear, and the interconnection between the receiver/stimulator and electrode array. The receiver/stimulator receives a radio frequency (rf) signal transmitted from an external transmitter, decodes the rf signal, and generates and delivers electric current to the electrodes according to the decoded information.

Both amplitude and frequency information are important in the perception of speech. While the intensity of a hearing sensation can be related to the strength of an electrical stimulation, providing satisfactory pitch perception is a more complicated problem. At low frequencies (below about 500 Hz), the rate of nerve firing, and hence the repetition frequency of the stimulating electrical pulses, is important. However, it has been shown that the physical location of the excited nerves inside the cochlea is largely responsible for the pitch of the hearing sensation above this range.

Further investigations of the receiver/stimulator section determined that it would be advantageous to have a greater degree of control over the stimulation applied by each electrode.

It is also desirable, in this and other biomedical applications, as well as in the broader field of electrical signal control, to be able to ensure that the net current at a stimulating electrode or other circuit point is zero. One object of the present invention is to provide a control

means whereby the signal at a particular point may be better controlled.

It is a more specific object of the present invention to provide an improved receiver/stimulator which enables greater control of the applied stimulation.

In its broadest aspect, the present invention provides an electrical signal control means comprising means for receiving a transmitted data signal, means for decoding the received signal, means for generating and delivering current signals to a desired point in a circuit according to the decoded information, characterized by means for actively controlling said current signal to deliver or return a predetermined amount of said current signal whereby the net current at the desired point is controlled.

More specifically, the invention provides a receiver/stimulator for a hearing prosthesis comprising means for receiving a transmitted data signal, means for decoding the received signal, means for generating and delivering current signals to a multiplicity of implanted electrodes according to the decoded information, characterized by means for actively controlling each electrode to deliver or return a predetermined amount of said current signals whereby the current distribution along the multiplicity of electrodes is controlled.

Alternatively, any group of the multiplicity of electrodes may be switched to a common voltage node which does not limit the electrode current but permits controlled current from other electrodes to flow through it in either direction. These two forms of stimulation, known as "bipolar" and "common-ground" may be set up on different groups of electrodes simultaneously.

The amplitude of the electrode current generated by each output-stage is determined by the voltage set by a 256-level digital-to-analogue converter, which is a central part of the preferred integrated-circuit design. The relationship between electrode current and the controlling

binary data from the speech processor is exponential, with a maximum current amplitude of about 2 milliamps. Another circuit, used in the electrode-voltage monitoring sub-system as well as in the receiver/stimulator output-stages provides a bidirectional analogue switch exhibiting low 'ON'-resistance and wide operating voltage-range. In the output-stages these switches provide the 'common ground' electrode connection.

Hearing sensations of the desired loudness and pitch are evoked by continuously transmitting control signals to the digital-to-analogue converter and the output-stages of the implanted receiver/stimulator. For safety, the data to the receiver/stimulator must be refreshed frequently so that occasional errors have a minimal effect on nerve stimulation. As most digital and analogue signals are stored temporarily as electric charges in this design, inadequate or erroneous data will result in the receiver/stimulator reverting to a quiescent state in which no electrode current is permitted to flow.

The active manipulation of the current distribution along the length of the scala tympani is an important factor in the operation of a hearing prosthesis because it has been established in psychophysical studies that the timbre of the hearing sensation is closely related to the distribution of current in the scala tympani.

In another aspect of the present invention, there is provided a receiver/stimulator for a hearing prosthesis comprising means for receiving a transmitted data signal, means for decoding the received signal, means for generating and delivering current signals to a multiplicity of implanted electrodes according to the decoded information, characterized by means for monitoring the voltage and/or current levels at one or more of said implanted electrodes, and means for utilizing the voltage and/or current information to check the integrity of the output stages controlling the currents delivered to the electrodes and/or to monitor the biological potentials generated within the peripheral auditory system.

The measurement of biological potentials, such as the action potential of the auditory nerve in response to electrical stimulation, provides information about the behaviour of the peripheral auditory system. The biological information can be used to modify the amount of current to be delivered to individual electrodes. In addition, the biological information can also be related to psychophysical and speech testing results to achieve further improvements in the hearing prosthesis design.

Preferably a single electrode is selected to act as a voltage probe, whether or not it is actively involved in stimulation at the time, the voltage being measured relative to system ground. Any one of the multiplicity of electrodes may be selected and different electrodes may be selected for different purposes. Alternatively, the voltage difference between any two selected electrodes may be measured.

Information derived by this means can be fed back to the circuitry controlling the stimulation so that the stimulus parameters may be optimised.

It is preferred that the first and second aspects of the invention be combined in a single receiver/stimulator system, as will be described in greater detail with reference to the preferred embodiment shown schematically in the block diagram of the accompanying drawing.

In the past, hearing prostheses have used one of the following three modes of stimulation: monopolar, common ground or bipolar stimulation. In the following descriptions it is assumed that a multiple-electrode array has been implanted in the scala tympani. In monopolar stimulation the electrodes in the scala tympani are "active" with respect to a single ground electrode located in a remote site (such as an arm or the promontory) away from the scala tympani electrodes. For common ground stimulation alternate scala tympani electrodes are connected to ground, and are interspersed between active electrodes. In bipolar stimulation electric current is passed between two scala tympani electrodes; a number of such bipolar electrode pairs can be used in a hearing prosthesis. It is generally accepted

that bipolar stimulation provides the best control of the current distribution in the scala tympani. However, isolated current sources are required for the stimulation of a large number of bipolar electrode pairs. Active sourcing and sinking

of electrode currents provided by the present invention permits electrical nerve stimulation to be effected and simultaneously controlled at several sites in the scala tympani.

Referring now to the block diagram, which shows one design of a receiver/stimulator system embodying the two aspects of the invention described above, digital control signals and electric power are transferred from an external speech processor/transmitter across a transcutaneous inductive link. The received radio frequency signal is processed by the "power supply" circuit block to provide power to the receiver/stimulator system. Clock and control signals are generated by the "clock generator" and the "end of data sequence detector". In the present design, a sequence of 57 data bits is received about every 10 microseconds. It is partitioned into an 8-bit word controlling an on-chip digital-to-analogue converter, and fifteen 3-bit segments which set the state of the fifteen output stages so that active sourcing and sinking can be effected. The remaining four bits select one electrode voltage to be measured and transmitted over a telemetry channel for external monitoring. An electrode voltage measured during the occurrence of a stimulus current pulse reflects the current flowing through the electrode, while a voltage measured when the electrode is inactive would correspond to a biological potential produced by the peripheral auditory system.

Further description of the individual components of the receiver/stimulator shown in the block diagram will now be provided.

All the input data to receiver/stimulator passes through the 57-bit shift-register. It is a standard design having a 2-phase clock and long depletion-mode load transistors for low power consumption. Both the available true and complementary parallel outputs are used by most of the decoding circuits. An additional 1-bit stage is added to the input for compatability with the external timing generator, and the output of the last stage is buffered and brought to a pad for testing. The required maximum clock

frequency is about 12 MHz.

The digital-to-analogue converter (DAC) is based on the tapped resistor-string technique as this guarantees a monotonic transfer-function. The resistance is formed in the diffusion layer and its value increases progressively along its length so that the voltage generated is related exponentially to the 8-bit input word. An exponential relationship is used because the loudness of the hearing sensations produced by electrical stimulation is a power function of electric current. A network of 510 transistor-switches form a binary tree structure to select one tap on the resistor to produce the desired output voltage. The width of the transistors doubles for each more-significant bit so that the total gate capacitance remains constant and the effective series resistance of about 20 kilohm is independent of the size of the DAC. The layout is selected to ensure that the rise-time at the output (about 2 microseconds) is approximately independent of the input data.

All digital data in the receiver/stimulator shift-register is latched in parallel onto dynamic storage nodes by the ENABLE input. A non-inverting superbuffer having a ratio of 3:1 for good rise-time drives that 16 true and complementary inputs of the DAC.

In the electrode voltage monitor selector, a 4-bit input from the shift-register sets one of 16 outputs high while the others are held low. This function is performed for each output by a 4-input NOR gate. A high-level output of 10 V is generated by this module so that it can directly drive the 16 analogue switches described below. Fifteen of these switches are connected to the electrodes while the sixteenth selects the DAC output voltage for testing the behaviour of that design. The selected analogue voltage is transferred to the 'Monitor Output' pad for connection to a telemetric feedback system.

The telemetry system includes an oscillator whose frequency is modulated in proportion to the selected electrode voltage. The modulated signal, which has a centre frequency of about 25 MHz, is transmitted from the receiver/stimulator to

an external demodulator which recovers the electrode voltage. This voltage can then be monitored or processed further to provide feedback control signals to the speech processor/transmitter.

Each of the 15 output modules may be independently set to one of 5 modes of operation by 3 bits of stored data from the main shift-register. The possible functions are:

SOURCE: Controlled current, up to 2 mA, flows from the stimulator into the appropriate electrode.

SINK: Controlled current flows from the electrode into the stimulator.

RESET: Electrode current is unconditionally set to zero.

COMMON: The electrode is switched onto a low-impedance node which is common to all outputs. Unlimited current from other electrodes may then flow in either direction with respect to this node.

NOP: If the output-stage was in the source, sink or reset state when the NOP instruction is decoded, then that previous state is maintained. This allows the DAC to be time-shared among the various outputs so that currents at different levels may be generated simultaneously. The COMMON state is not held after a NOP input.

A voltage proportional to the amplitude of the electrode current is developed by a resistor. This voltage is compared with the DAC voltage by a transistor. The capacitance on the gate of one of two large output transistors is then charged if the output current is below the desired value. The electrode current cannot be reduced by this integrating feedback mechanism: the output-stage must be RESET when the electrode current pulse is to be terminated. In the NOP stage the nodes controlling the output current are isolated and the associated analogue voltages are stored for up to 100 microseconds until the DAC is next available for a refresh operation.

A digital decoder which sets each output-stage stage includes a 3-bit decoder which may take on 8 distinct states.

The 5 valid modes of operation have been allocated so that a one-bit error will not cause catastrophic changes in the electrode current. Note also that a RESET occurs whenever the COMMON state is selected. The decoder is included in all 15 output modules.

This prototype receiver/stimulator has been implemented using nMOS technology, although it will be implemented in CMOS technology which is more suited to biomedical applications.

The claims defining the invention are as follows:

1. An electrical signal control means comprising means for receiving a transmitted data signal, means for decoding the received signal, means for generating and delivering current signals to a desired point in a circuit according to the decoded information, characterized by means for actively controlling said current signal to deliver or return a predetermined amount of said current signal whereby the net current at the desired point is controlled.

2. A receiver/stimulator for a hearing prosthesis comprising means for receiving a transmitted data signal, means for decoding the received signal, means for generating and delivering current signals to a multiplicity of implanted electrodes according to the decoded information, characterized by means for actively controlling each electrode to deliver or return a predetermined amount of said current signals whereby the current distribution along the multiplicity of electrodes is controlled.

3. The receiver/stimulator of claim 2, wherein any group of said multiplicity of electrodes is connected to a common voltage node which permits controlled current to flow from other electrodes through a selected electrode in either direction.

4. The receiver/stimulator of claim 2 or 3, wherein the means for decoding the received signal includes a digital-to-analogue converter having an exponential transfer function.

5. A receiver/stimulator for a hearing prosthesis comprising means for receiving a transmitted data signal, means for decoding the received signal, means for generating and delivering current signals to a multiplicity of implanted electrodes according to the decoded information, characterized by means for monitoring the voltage and/or current levels at one or more of said implanted electrodes, and means for utilizing the voltage and/or current information to check the integrity of the output stages controlling the currents delivered to the

electrodes and/or to monitor the biological potentials generated within the peripheral auditory system.

6. The receiver/stimulator of claim 5, wherein one of said electrodes is connected to act as a voltage/current probe, irrespective of whether it is stimulating or not.

7. The receiver/stimulator of claim 5, wherein two electrodes act as voltage probes, the voltage difference between the two being measured.

8. The receiver/stimulator of claims 1, 2, 3 or 4, further comprising the voltage/current monitoring means of claim 5, 6 or 7.

9 The receiver/stimulator of any one of claims [illegible] substantially as hereinbefore described with reference to the accompanying drawing.

10. A receiver/stimulator for a hearing prosthesis, substantially as hereinbefore described with reference to the accompanying drawing.

DATED this 22nd day of AUGUST, 1983.

THE UNIVERSITY OF MELBOURNE

By its Patent Attorneys:

SANDERCOCK, SMITH & BEADLE

Fellows Institute of Patent Attorneys of Australia.

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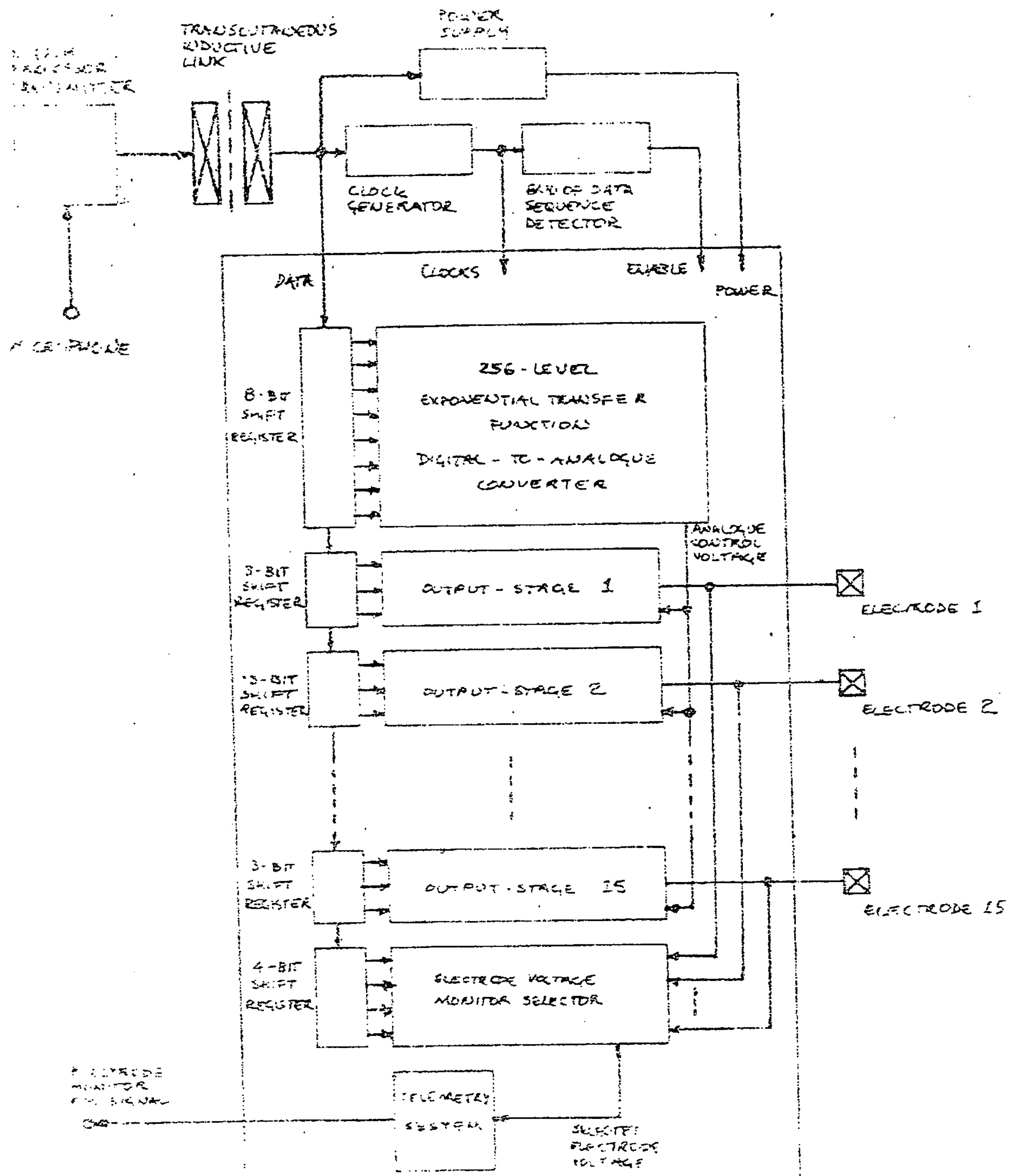
TRANSCUTANEOUS INDUCTIVE LINK
POWER SUPPLY
CLOCK GENERATOR
END OF DATA SEQUENCE DETECTOR
DATA
CLOCKS
ENABLE
POWER
8-BIT SHIFT REGISTER
256-LEVEL
EXPONENTIAL TRANSFER FUNCTION
DIGITAL-TO-ANALOGUE CONVERTER
ANALOGUE CONTROL VOLTAGE
3-BIT SHIFT REGISTER
OUTPUT-STAGE 1
ELECTRODE 1
3-BIT SHIFT REGISTER
OUTPUT-STAGE 2
ELECTRODE 2
3-BIT SHIFT REGISTER
OUTPUT-STAGE 15
ELECTRODE 15
4-BIT SHIFT REGISTER
ELECTRODE VOLTAGE MONITOR SELECTOR
TELEMETRY SYSTEM
SELECTED ELECTRODE VOLTAGE